Texture Mapping
Reading

Optional

- Angel and Shreiner: 7.4-7.10
- Marschner and Shirley: 11.1-11.2.3, 11.2.5, 11.4-11.5

Further reading

- Woo, Neider, & Davis, Chapter 9
Texture mapping

Texture mapping allows you to take a simple polygon and give it the appearance of something much more complex.

- Due to Ed Catmull, PhD thesis, 1974
- Refined by Blinn & Newell, 1976

A texture can modulate just about any parameter – diffuse color, specular color, specular exponent, ...
Implementing texture mapping

A texture lives in its own abstract image coordinates parameterized by \((u, v)\) in the range \([0..1], [0..1]\):

It can be wrapped around many different surfaces:

With a ray caster, we can do the sphere and cylinder mappings directly (as we will see later). For graphics hardware, everything gets converted to a triangle mesh with associated \((u, v)\) coordinates.

Note: if the surface moves/deforms, the texture goes with it.
Texture coordinates on a surface of revolution

Recall that for a surface of revolution, we have:

**Profile curve**: \( C[j] \) where \( j \in [0..M-1] \)

**Rotation angles**: \( \theta[i] = 2\pi i / N \) where \( i \in [0..N] \)

The simplest assignment of texture coordinates would be:

\[
U = \frac{i}{N}
\]

\[
V = \frac{j}{M-1}
\]

Note that you should include the rotation angles for \( i = 0 \) and \( i = N \), even though they produce the same points (after rotating by 0 and 2\( \pi \)). Why do this?
Texture coordinates on a surface of revolution

If we wrap an image around this surface of revolution, what artifacts would we expect to see?

We can reduce distortion in \( v \). Define:

\[
    d[j] = \begin{cases} 
        \| C[j] - C[j-1] \|, & \text{if } j \neq 0 \\
        0, & \text{if } j = 0 
    \end{cases}
\]

and set \( v \) to fractional distance along the curve:

\[
    v = \frac{\sum_{k=0}^{j} d[k]}{\sum_{k=0}^{n-1} d[k]}
\]

You must do this for \( v \) for the programming assignment!
Mapping to texture image coords

The texture is usually stored as an image. Thus, we need to convert from abstract texture coordinate:

\[(u, v)\] in the range \([0..1], [0..1]\)

to texture image coordinates:

\[(u_{\text{tex}}, v_{\text{tex}})\] in the range \([0.. w_{\text{tex}}], [0.. h_{\text{tex}}]\)

Q: What do you do when the texture sample you need lands between texture pixels?
Texture resampling

We need to resample the texture:

Thus, we seek to solve for $T(a, b) = T(i + \Delta x, j + \Delta y)$

A common choice is bilinear interpolation:

$$T(i + \Delta x, j) = (1 - \Delta x)T[i, j] + \Delta x T[i + 1, j]$$

$$T(i + \Delta x, j + 1) = (1 - \Delta x)T[i, j + 1] + \Delta x T[i + 1, j + 1]$$

$$T(i + \Delta x, j + \Delta y) = (1 - \Delta y)T(i + \Delta x, j) + \Delta y T(i + \Delta x, j + 1)$$

$$= (1 - \Delta x)(1 - \Delta y)T[i, j] + \Delta x \Delta y T[i + 1, j] + \Delta x T[i + 1, j + 1]$$

$$+ (\Delta x \Delta y)T[i + 1, j + 1]$$
Texture mapping and rasterization

Texture-mapping can also be handled in rasterization algorithms.

Method:

- Scan conversion is done in screen space, as usual
- Each pixel is colored according to the texture
- Texture coordinates are found by Gouraud-style interpolation

Note: Mapping is more complicated to handle perspective correctly.
Displacement mapping

Textures can be used for more than just color.

In **displacement mapping**, a texture is used to perturb the surface geometry itself. Here’s the idea in 2D:

- These displacements “animate” with the surface
- In 3D, you would of course have \((u, v)\) parameters instead of just \(u\).

Suppose \(Q\) is a simple surface, like a cube. Will it take more work to render the modified surface \(\tilde{Q}\)? ~
Bump and normal mapping

In **bump mapping**, a texture is used to perturb the normal:

- Use the original, simpler geometry, \( Q(u) \), for hidden surfaces
- Use the normal from the displacement map for shading:

\[
\tilde{N} = \text{normal}[\tilde{Q}(u)]
\]

An alternative is to compute the normals from the original bump map height field and map them over the smooth surface. This is called **normal mapping**.

What artifacts in the images would reveal that bump (or normal) mapping is fake?
Displacement vs. bump mapping

Input texture

Rendered as displacement map over a rectangular surface
Displacement vs. bump mapping (cont'd)

Original rendering  Rendering with bump map wrapped around a cylinder

_Bump map and rendering by Wyvern Aldinger_
Solid textures

Q: What kinds of artifacts might you see from using a marble veneer instead of real marble?

One solution is to use **solid textures**:

- Use model-space coordinates to index into a 3D texture
- Like “carving” the object from the material

One difficulty of solid texturing is coming up with the textures.
Solid textures (cont’d)

Here's an example for a vase cut from a solid marble texture:

*Solid marble texture by Ken Perlin, (Foley, IV-21)*
Solid textures (cont'd)

\[
\begin{align*}
\text{in}(x, y, z) &= \text{stripes}(x) \\
\text{shift}(x, y, z) &= K \cdot \text{noise}(x, y, z) \\
\text{out}(x, y, z) &= \text{stripes}(x + \text{shift}(x, y, z))
\end{align*}
\]
Environment mapping

In **environment mapping** (also known as **reflection mapping**), a texture is used to model an object's environment:

- Rays are bounced off objects into environment
- Color of the environment used to determine color of the illumination
- Environment mapping works well when there is just a single object – or in conjunction with ray tracing

This can be readily implemented (without interreflection) in graphics hardware using a fragment shader, where the texture is stored in a “cube map” instead of a sphere.

With a ray tracer, the concept is easily extended to handle refraction as well as reflection (and interreflection).
Summary

What to take home from this lecture:

1. The meaning of the boldfaced terms.

2. Familiarity with the various kinds of texture mapping, including their strengths and limitations.